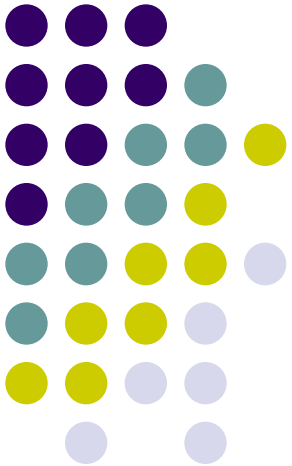
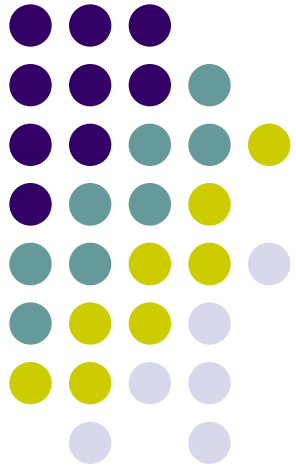
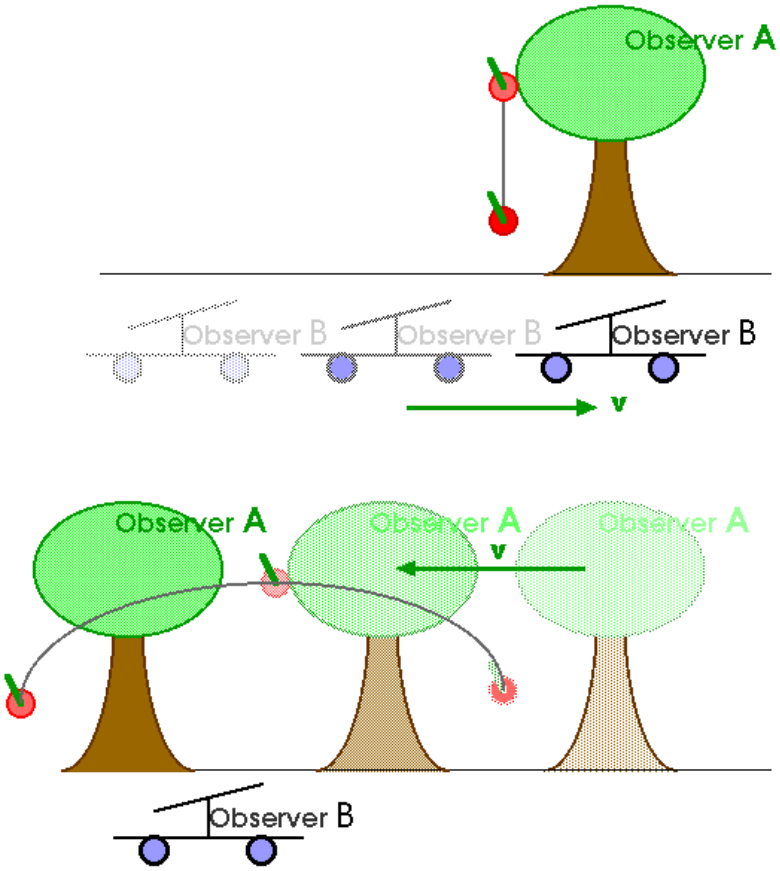
Newtonian Cosmology II



Invariance vs Relativity



Galilean Relativity



Galilean Relativity

- A physical quality is said to be:
  - **invariant**, if different *inertial* observers would obtain the same result from a measurement of this quantity. Example: the mass of an object.
  - **relative**, if different *inertial* observers would obtain different result from a measurement of this quantity. Example: the speed of an object.

- The principle of **Galilean relativity** states that Newton's laws of motion are the same in all inertial frames of reference.

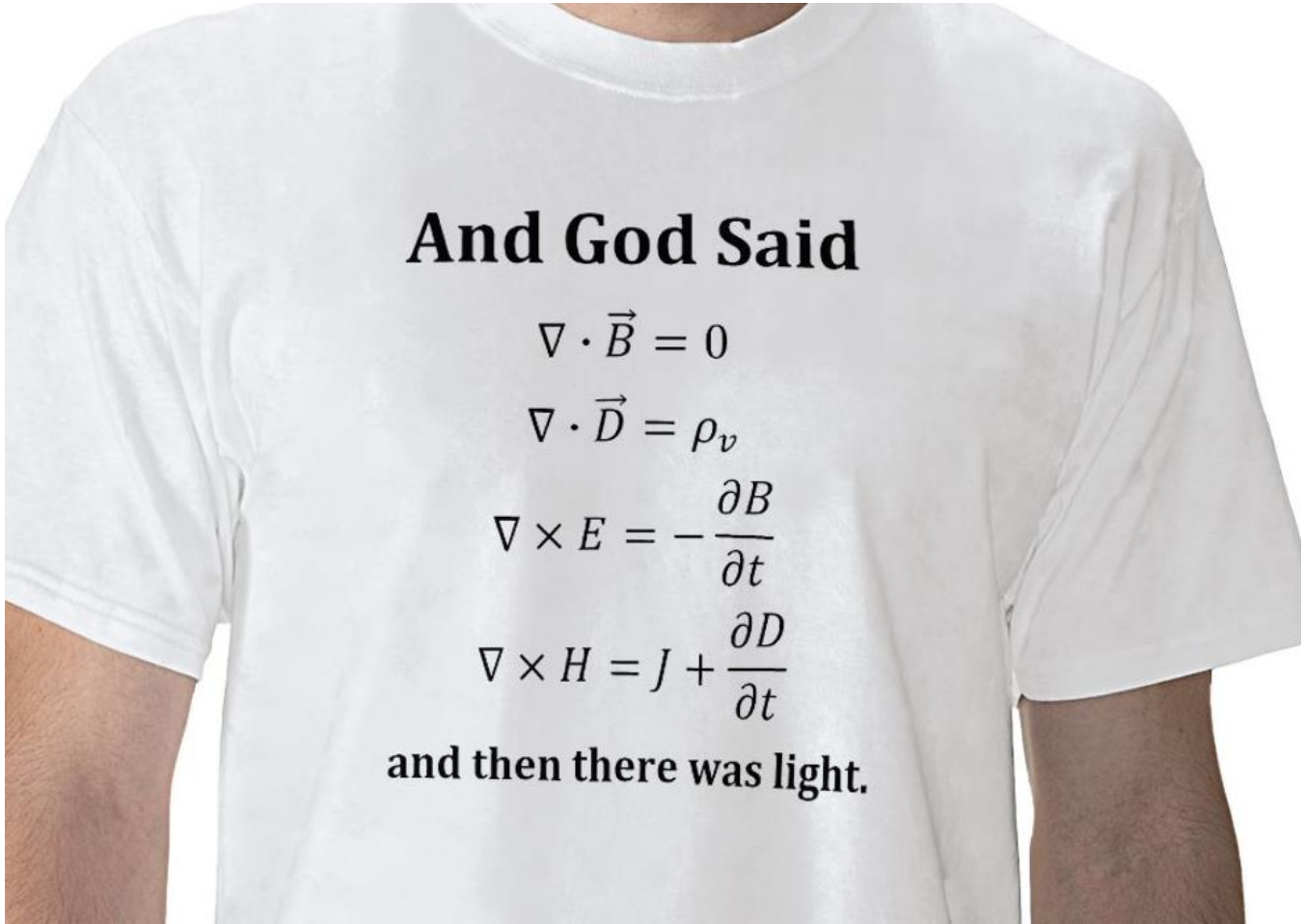
- Until about 1860s, the Newtonian physics was considered completed, giving the ultimate and final description of the universe. (Recall, what Aristotle thought about his teaching?)

James Maxwell (1831 – 1879)

- Finalized the work of others on electricity and magnetism.
- He formulated ***Maxwell Equations*** for the ***electromagnetic field***.
- His equations predicted the existence of ***electromagnetic waves*** that propagated with the speed of light.

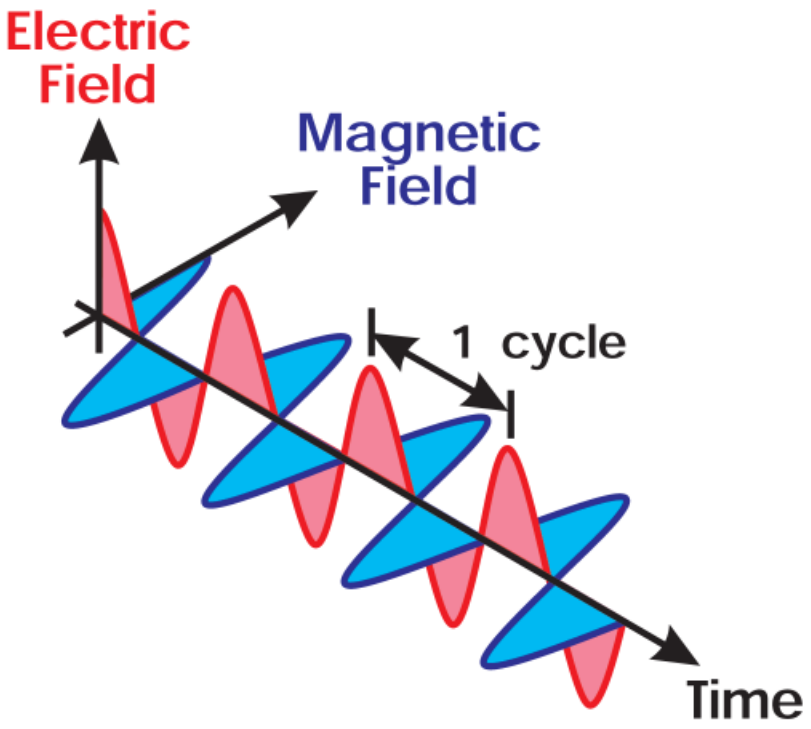
"The agreement of the results seems to show that light and magnetism are affections of the same substance, and that light is an electromagnetic disturbance propagated through the field according to electromagnetic laws."

Maxwell Equations



Electromagnetic waves

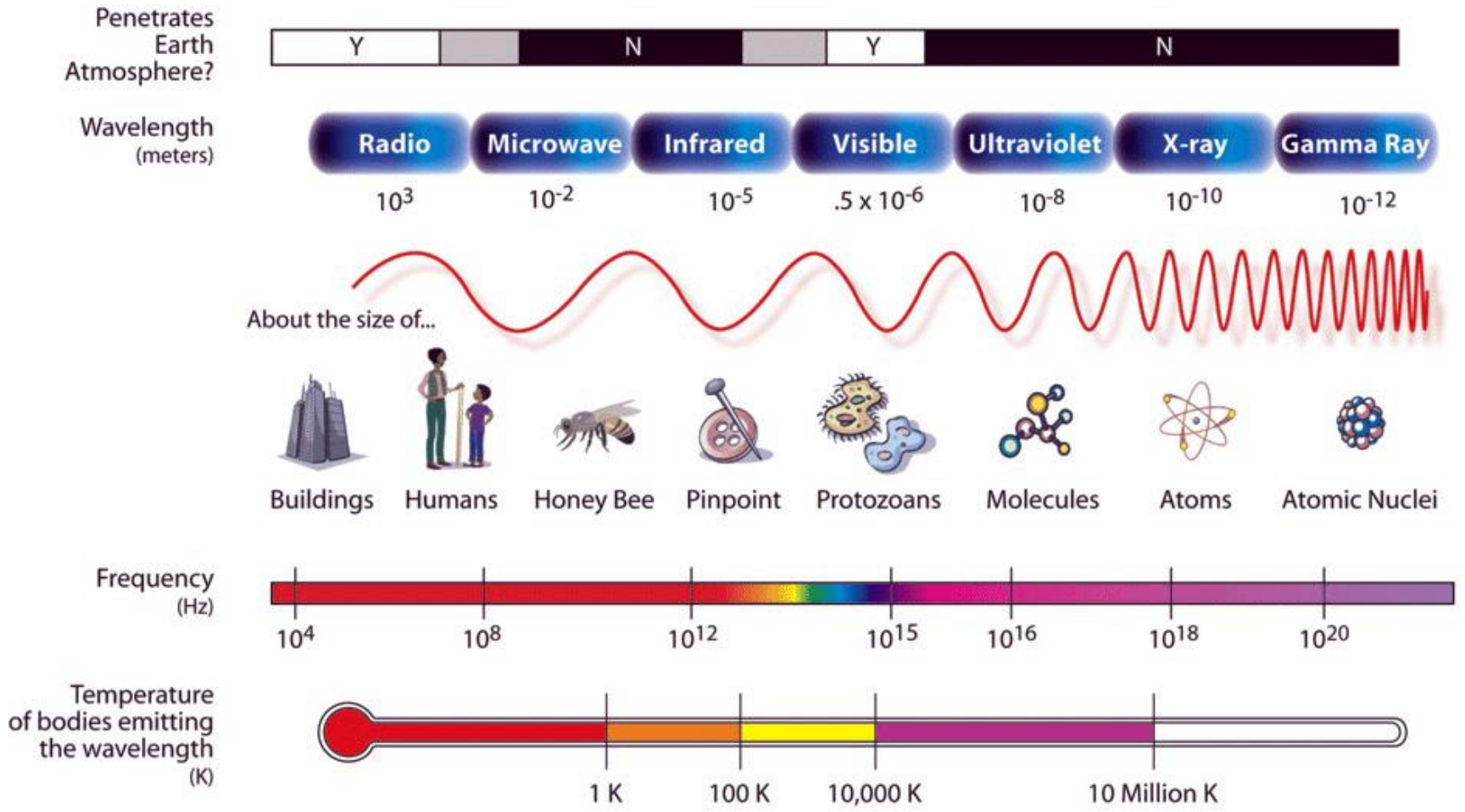
- They propagate in ***vacuum***.
- Waves of different frequencies move with the same speed, the speed of light ***c***.



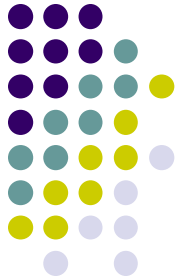
c = 299,792,458 m/s

= 1,079,252,849 km/h

Electromagnetic spectrum



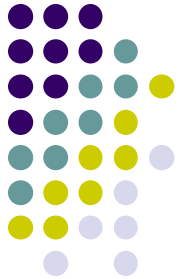
Speed of Light



- In Maxwell's theory *the speed of light is the same in all reference frames*, i.e. it is *invariant*, rather than *relative*. However, the principle of Galilean invariance states that the speed of anything, including light, is a relative quantity.
- The notion of waves propagating all by themselves, rather than in some medium (like sound waves in the air, ocean waves on the surface of the ocean etc) was also unusual to scientists, and thus disturbing.

Ether is Back

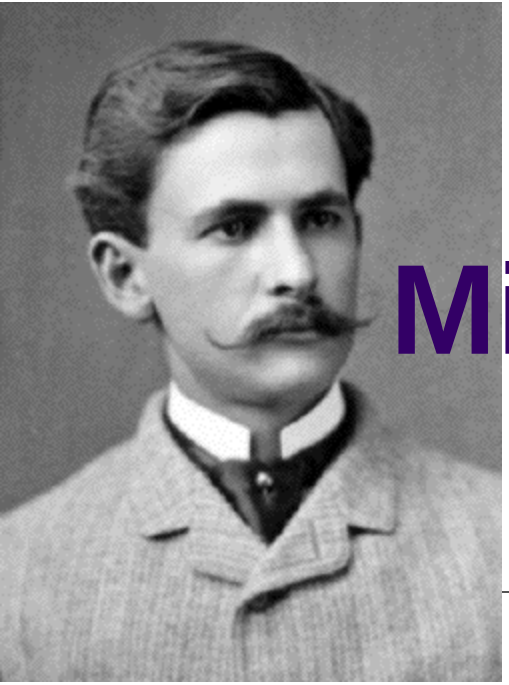
- A resolution was quickly discovered: light was propagating not by itself, but in a special medium called **luminiferous ether**. So, the ether came back.
- The luminiferous ether had no other reason for its existence than to provide the expected medium for the propagation of light.
- Ether was massless and invisible. It could not be directly detected in the lab.



It was generally assumed that the Maxwell equations were valid only in the frame of reference of this ether. Thus, the speed of light was equal to

$$\mathbf{c} = 299{,}792{,}458 \text{ m/s}$$

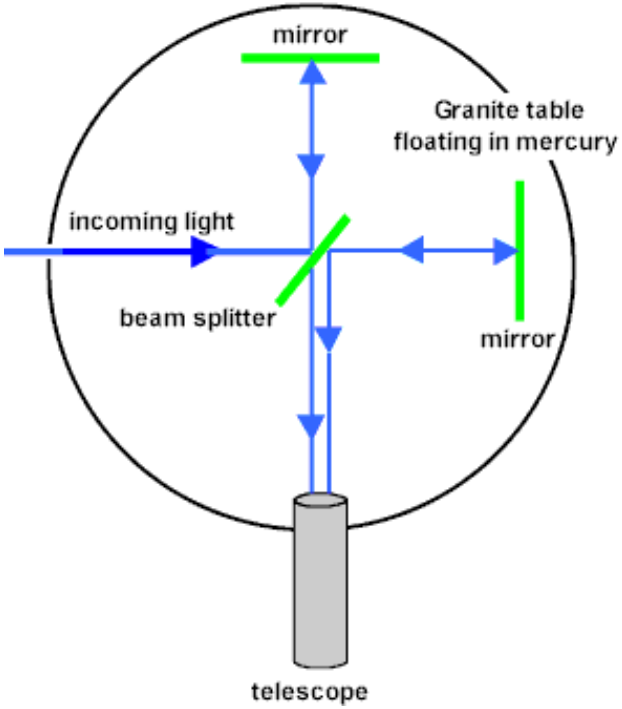
only in the ether frame of reference. In other inertial frames it would be different according to the principle of Galilean invariance. In particular, it should be different on the Earth which moves through the ether.

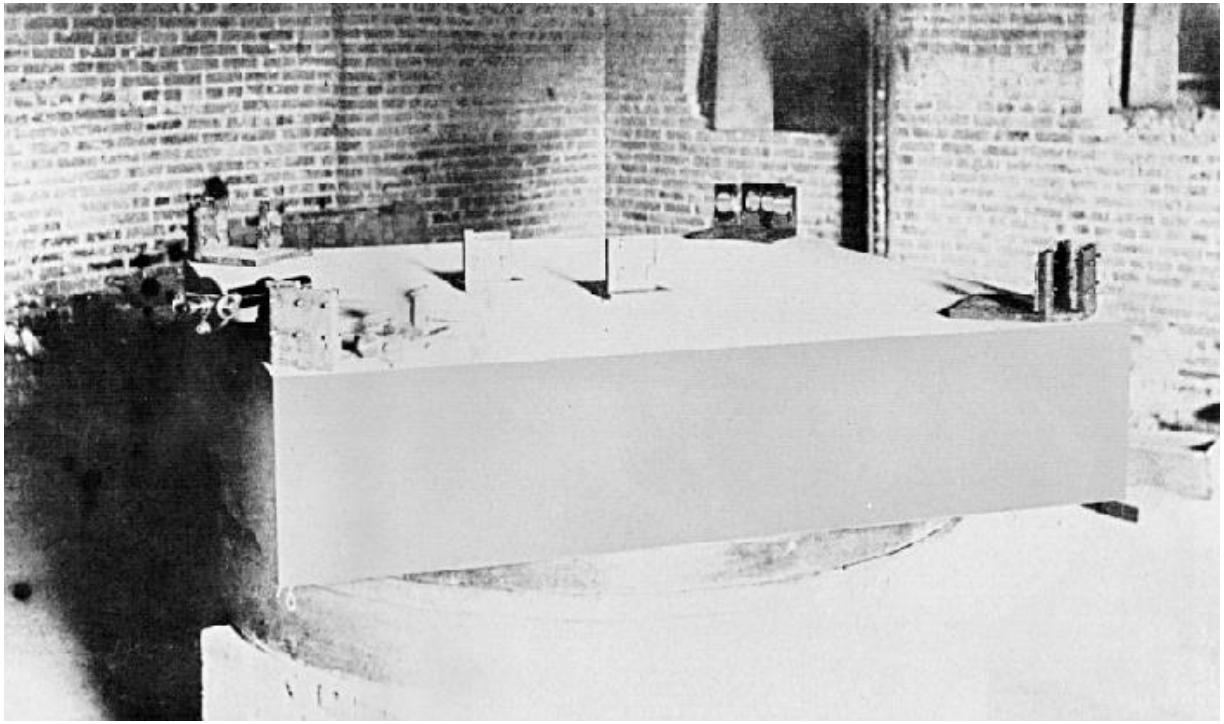


Michelson-Morley experiment

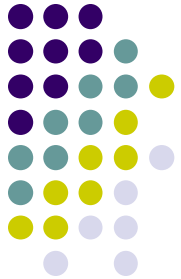
In 1887, two American physicists, ***Albert Michelson*** *and* ***Edward Morley*** *set out to measure the motion of the Earth with respect to the ether.*

Michelson-Morley experiment





- The result of their experiment was **negative**. They found that the speed of light along the Earth orbital direction was the same as the speed of light perpendicular to the Earth orbital direction to within 5 km/s (the accuracy of their measurement).
- Since the Earth orbital speed is about 30 km/s, the experiment clearly demonstrated that **the speed of light was the same in all reference frames**, in a clear contradiction to the principle of Galilean invariance. The ether was gone!
- Michelson still got his Nobel prize, though – he also was the first chair of the Physics Dept. at UChicago.



- Another problem with the standard physics was explaining the radiation of a parcel of highly heated gas, the so called **blackbody radiation.**
- From these two small ``clouds'' on a clean horizon of XIX century physics two hurricanes came: Einstein's theory of relativity and quantum mechanics.